

PATENT APPLICATION  
FOR  
MATRIX METHODS AND SYSTEMS FOR SUPPLY CHAIN MANAGEMENT  
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## DESCRIPTION OF THE INVENTION

### Cross-Reference to Related Applications

[001] This application claims priority benefits based on U.S. Provisional Application 60/193,693, filed March 31, 2000, the technical disclosure of which is incorporated herein by reference.

### Field of the Invention

[002] This invention relates generally to methods and systems for supply chain management and, more particularly, to methods and systems for supply chain management using bit storage and calculations.

### Background of the Invention

[003] In supply chain management, one goal is to have real time reaction up and down the supply chain. For example, many industries have moved to just-in-time models to supply parts to assembly line positions and warehouse inventories. Just-in-time supply models are cost efficient because they keep inventory low and allow quick reaction by the manufacturers to configuration changes. These same manufacturers, however, must constantly adjust the supply chain to ensure that no valuable production time is lost because an assembly line runs out of a necessary part. At the same time, customers have become more demanding and frequently demand an accurate promised delivery date of an ordered product. Often, the customer makes last minute changes to the configuration, yet still expects the same promised delivery date to be met.

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[004] Many manufacturers have complex product lines that comprise dozens of products with each product line requiring thousands of material components. For example, in automobile manufacturing most of the major producers carry a product line consisting of four to eight different models of automobiles. Design choices produce multiple combinations of possible automobiles. For instance, each automobile may come in six different exterior colors, three different interior colors, and three different model classes (such as low end, medium end, and deluxe). A typical automobile manufacturer produces very few cars with the exact same configuration. For instance, one European manufacturer has automobiles with over 300 different characteristics, each characteristic having up to five different values; thus, this manufacturer theoretically may have up to  $5^{300}$  different configurations. Manufacturers estimate that only between 2 and 8 cars have the same configuration.

[005] In the effort to maintain customer satisfaction by accurately predicting a delivery date, manufacturers also want to be able to quickly manage the supply chain so as to be able to react quickly to market preferences and changes forced by suppliers. If the manufacturer makes changes to the configuration or enhances the product, the manufacturer would like to put the product into production as soon as possible, without leaving excess inventory in the warehouse. Also, manufacturers must be able to react quickly to changes forced by suppliers to prevent gaps in the supply chain that change capacity restrictions or require orders to be rescheduled. Examples of such changes include a shortage of raw materials by suppliers, strikes, accidents or natural disasters. When such a change occurs, manufacturers would like to be able to react quickly by rescheduling all orders to reflect the change.

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[006] Conventional systems typically store configuration data in SQL tables in relational form. Operations on the database are performed using time-consuming SQL functions. With the sheer volume of configuration and customer order information, such databases are slow and unwieldy to update. The typical automobile manufacturer may handle, for example, up to 14 million orders over a typical year, with thousands of characteristic values, such as interior and exterior color, resulting in a large variance of configurations.

[007] Additionally, in conventional SQL systems, each order is stored using a different byte of information for each characteristic. Consequently, the order database must be large, and the writing and reading of such a large amount of information consumes a lot of run time and may require days to update. For this reason, the supply chain management systems of larger manufacturers often run updates to configurations and orders only every two weeks and limit the calculations to weekends. If updates are performed in real time, the system runs the risk of inaccurate supply levels or estimated delivery dates. In the automobile manufacturer example, for instance, hundreds of dealers are drawing from the same system at the same time. It is possible that dealers will promise a customer one delivery date based on old data, then when the database is updated see that the particular product is sold out and therefore have to disappoint the customer by changing the estimated delivery date.

### SUMMARY OF A FEW ASPECTS OF THE INVENTION

[008] In accordance with the invention, methods and system for generating an order matrix are provided that receives an order comprising one or more tokens out of a set of possible tokens, wherein a token is a combination of a characteristic and a value

of the characteristic. Order are placed in an order matrix, wherein the order matrix is at least a two dimensional data structure, each row of the data structure representing a possible token and each column of the data structure representing an order.

[009] Also, methods and systems for determining a production period for rescheduling a plurality of orders are given. The method first receives a plurality of orders having one or more tokens out of a set of possible tokens. Each token is a combination of a characteristic and a value of the characteristic. Next, an order restriction matrix is generated. The order restriction matrix is a two dimensional data structure with each row of the data structure representing a possible restriction and each column of the data structure representing an order. The method looks up the restrictions that apply to the orders and derives an order derived production restriction matrix for each order, which is evaluated to determine possible production periods for each order.

[010] Also, methods and systems for determining potential production periods for a potential order are given. The method receives an order having one or more tokens out of a set of possible tokens. Each token is a combination of a characteristic and a value of the characteristic. For the order, one or more restrictions are determined based on the tokens. This series of restrictions is used to generate an order derived production restriction matrix for the order, which is evaluated to determine possible production periods for the order.

[011] Also, methods and systems for generating a bill of materials for a production run are shown. The method receives a plurality of orders comprising one or more tokens out of a set of possible tokens, wherein a token is a combination of a

characteristic and a value of the characteristic. It places the orders in an order matrix, wherein the order matrix is at least a two dimensional data structure, each row of the data structure representing a possible token and each column of the data structure representing an order. Next, a bill of materials matrix is generated by evaluating the order matrix, wherein the bill of materials matrix is at least a two dimensional data structure, each row of the data structure representing a possible item and each column of the data structure representing an order.

[012] The foregoing summarizes only a few aspects of the invention and is not intended to be reflective of the full scope of the invention as claimed. Additional features and advantages of the invention are set forth in the following description, may be apparent from the description, or may be learned by practicing the invention. Moreover, both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[013] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate one embodiment of the invention and together with the description, serve to explain the principles of the invention.

[014] Figure 1 illustrates a flow chart of the supply chain management process for an exemplary embodiment of the present invention.

[015] Figure 2 illustrates an order matrix consistent with an embodiment of the present invention.

[016] Figure 3 illustrates an order restriction matrix in an exemplary embodiment of the present invention.

[017] Figure 4 illustrates a production restriction matrix in an exemplary embodiment of the present invention.

[018] Figure 5 illustrates an order derived production restriction matrix in an exemplary embodiment of the present invention.

[019] Figure 6 is a flow chart illustrating typical stages for generating an order derived production restriction matrix consistent with an embodiment of the present invention.

[020] Figure 7 illustrates a bill of materials matrix consistent with an embodiment of the present invention

[021] Figure 8 illustrates an effectivity matrix consistent with an embodiment of the present invention.

[022] Figure 9 is a flow chart illustrating typical stages for exploding an order matrix into a bill of materials matrix consistent with an embodiment of the present invention.

[023] Figure 10 is a plurality of tables illustrating a system of checking availability with historical selection conditions in which features and principles of the present invention may be implemented.

[024] Figure 11 illustrates a system environment in which the features and principles of the present invention may be implemented.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

[025] Reference will now be made in detail to the present exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[026] The present invention recites methods and systems for supply chain management using bit matrix calculations and storage of data. In an exemplary embodiment, the storage of data is done in matrix form using bit arrays. Each order, for example, can be described using a set of tokens. A "token" is a combination of a characteristic and the value for that characteristic. In the automobile example, a customer may order an auto that is either red, green, or blue. The transmission may be "standard" or "automatic" and model may be perhaps "basic," "regular," or "luxury." In this example, color, transmission and model are all characteristics. If a customer chooses an auto that is red, with standard transmission, in a luxury model, the order will consist of three tokens: (color = red), (transmission = standard), and (model = luxury).

[027] Figure 1 illustrates a flow chart of the supply chain management process for an exemplary embodiment of the present invention. Supply chain management process 100 begins at stage 110 with a customer requesting an order of a good or service. Throughout this description of the invention, automobiles will be the example used; however, this invention is not limited to automotive processes or goods. At stage 120, the order is entered into the system or a request for a delivery date is entered. At stage 130, the availability to promise (ATP) process determines the potential delivery date for the goods. The delivery date is confirmed with the customer at stage 110, and if the delivery date is unacceptable, the process 100 returns to stage 110 so that the

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## Rescheduling

[029] The initial placement of orders may be performed through the ATP, Availability to Promise, methods described in the next section. Restrictions, comprising bottleneck resources or components, may change after production orders are placed. Capacities may change; supplier delivery may fluctuate; selection conditions may need to be altered; orders may be canceled freeing up capacity within the system; and priority orders may need to be inserted. For example, a selection condition at a restriction level may change. For instance, "Air Conditioning" may be a restriction. If air conditioning was initially an option and later becomes a standard part, this leads to a change in the selection condition of the restriction "Air Conditioning." If any of these changes occur, rescheduling may take place.

[030] As an introduction, in order to perform a rescheduling process, the original available capacity for all restrictions is adjusted to reflect the additional capacity generated as placed orders are removed from the schedule for rescheduling. A new order restriction matrix is generated with new selection conditions accounted for. Next, the orders are rescheduled using the new order restriction matrix.

[031] In order to determine revised production dates for a plurality of customer orders, the customer orders, from the order matrix 200, are checked against the selection criteria to determine what, if any, restrictions apply to the order. Restrictions describe available capacity of a resource or a bottleneck component for a particular period of time, such as a shift or a day.

[032] Figure 3 illustrates an order restriction matrix in an exemplary embodiment of the present invention. Order restriction matrix 300 has columns 310a – 310n representing each order; rows 320a – 320n represent restrictions. Each restriction

bit vector 320 has an associated function (selection criteria) for evaluating one or more token bit vectors 220. For each function, the appropriate token bit vectors 220 from order matrix 200 are combined according to the boolean function defined by the selection criteria function. This operation is on a bit vector level, so it is performed very fast because, in the exemplary embodiment of the invention, it is performed at the machine code level. Complex database or SQL calls are not required. For example, restriction bit vector 320a may have associated with it the function, restriction bit vector 320a = Token2 AND Token6. The first restriction bit vector 320a is evaluated. The order restriction matrix explosion process determines if any more restriction bit vectors 320 remain. If so, the next restriction bit vector 320 is evaluated. If not, the process stops and the order restriction matrix 300 is complete. For each order, the appropriate restrictions for any given order can be returned from the matrix by evaluating which rows of an order have a "1". Any given order may have hundreds of applicable restrictions. The restrictions for a given order are compared to a production restriction matrix to determine candidates for a production period.

[033] Figure 4 illustrates a production restriction matrix in an exemplary embodiment of the present invention. Production restriction matrix 400 comprises columns 410a – 410n representing time periods, such as days, shifts, or any appropriate measure. Rows 420a – 420n comprise restriction vectors and correspond to the restrictions 320a – 320n of order restriction matrix 300. Within each cell of production restriction matrix 400, a value is placed indicating the number of units that are free for production for that restriction 420 in that time period 410. The restrictions for each restriction vector 420 are evaluated to see if any time delay needs to be added



restriction vectors 420 from the production restriction matrix 400. This occurs in the exemplary embodiment by consulting the order restriction matrix 300 for an order and checking for entries of "1" which corresponds to a restriction that must be met.

[036] As the restriction vectors 520 are being identified, the second vector, an evaluation bit vector 530a – 530n, is identified based on the corresponding vectors 430 from the production restriction matrix 400. In order to determine possible production dates for the given order, the evaluation bit vectors 530 are ANDed into a result bit vector 540 that shows potential production periods. This operation on bit vectors yields rapid results because of the speed of bit calculations, which are performed in machine code in the exemplary embodiment of the invention. While the above description discusses the ODPRM 500 as being a table, in the exemplary embodiment of this invention the ODPRM 500 may be a virtual table comprising pointers to the corresponding vectors of PRM 400. In this fashion, memory and time are saved by not duplicating data entries. The generation of the ODPRM will be more fully explained below.

[037] Figure 6 is a flow chart illustrating typical stages for generating an order derived production restriction matrix consistent with an embodiment of the present invention. ODPRM process 600 commences at stage 610 by reading the list of restrictions for a given order from the order restriction matrix 300. At stage 620, the corresponding restriction vectors 420 from the production restriction matrix 400 are identified to the ODPRM 500. At stage 630, the corresponding evaluation bit vectors 430 from the production restriction matrix 400 are identified to the ODPRM 500. At stage 640, the ODPRM process 600 logically ANDs the evaluation bit vectors to

generate a result bit vector 540. The result bit vector contains all of the possible time periods of possible production.

[038] Thus, at a glance the earliest, latest, or production date closest to the desired delivery date can be determined for each order. The above process is repeated during a rescheduling for each order in order matrix 200 that meets a particular criteria, e.g. rescheduling every order in the next two week period. When an order is actually rescheduled, the appropriate entries in the production restriction matrix 400 are decremented by the appropriate count.

#### Availability to Promise (ATP)

[039] It is also useful to be able to determine an available delivery time for a customer order. In order to find an available delivery time, a suitable production date must be calculated followed by the addition of safety and transport times. This yields a confirmed delivery date. In order to determine a production date for a customer order, the customer order is checked against the selection criteria to determine what, if any, restrictions apply to the order. Restrictions describe available capacity of a resource or a bottleneck component for a particular period of time, such as a shift or a day.

[040] The ATP process is the same as the above Rescheduling Process except that it is done for a single order. There is no need to generate an order matrix 200 or a restriction matrix 300. As an order is entered by the requesting party, a token bit vector associated with the order will be converted to a restriction bit vector (not a restriction matrix). This restriction bit vector is then used to generated the ODPRM 500 for the single order. An order can then be placed in the appropriate period as explained above with reference to Figure 5.

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[041] It should be noted throughout these processes that reuse of information wherever possible is desirable. For instance, once a restriction vector is generated for an order in the order process, or at any time, the restriction vector may be reused, e.g., in the rescheduling process.

#### Supply Chain Planning

[042] Once an order is placed, a bill of materials matrix is used for supply chain planning. Figure 7 illustrates a bill of materials matrix consistent with an embodiment of the present invention. The order matrix may be projected to generate the set of material requirements for the orders. This process is described herein as "exploding" the order matrix to obtain the bill of materials (BOM) matrix 200. Each column 710a – 710n in the BOM matrix 700 represents an order (corresponding to the orders 110a – 110n in the order matrix 100; each row 720a – 720n in the matrix represents an item. Each item 720 denotes some or all of the following information: component information, effectivity date, and/or selection condition. Component information may include material number, quantity, restriction number, activity number or any other information regarding the component. The effectivity date is the date on which an item is available and contains values representing a validity start point and a validity end point. Selection condition is a logical function applied to item values, e.g., Token1 AND Token5 OR NOT Token18.

[043] In general, the order matrix 100 is exploded in the bill of materials matrix 700 as follows, with a more detailed discussion of the process to be discussed later. For example, each order for a luxury model red car with standard transmission will require that 100,000 different individual components be on hand. The list of individual





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explosion process 900, the bill of materials for each order can be accessed and utilized by simply reading an order (column) entry.

[048] Because of the rapid execution of BOM explosion process 900 due to its logical evaluation of bit arrays, the process 900 may be re-executed as orders change, new orders are added, effectivity dates change, or selection condition change without requiring downtime or a loss of production while waiting for complex processing of data as in the prior art.

[049] The BOM may be used in a wide variety of production and inventory planning functions. The BOM can be used to automatically order materials from just-in-time suppliers or to automatically decrement inventory counts in the warehouse or production line as completed orders are processed out of a production facility.

#### Historical Change in Selection Conditions

[050] Selection conditions at a restriction level may change over time which causes complications in both the ATP process and the rescheduling process. For instance, alloy wheels may be a restriction tied to a sports package, but not a luxury package, for a car during the first half of the year; but, during the second half of the year alloy wheels become a restriction tied to a luxury package, but no longer a sports package. If an order for a sports package is scheduled for production during the first half of the year, alloy wheels will be required; however, if the sports package is scheduled for the second half of the year, alloy wheels are not required. Similarly, if an order for a luxury package is scheduled for production during the first half of the year, alloy wheels are not required; however, if the luxury package car is scheduled for production during the second half of the year, alloy wheels are required. This poses a

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as a mask. For periods in which the effectivity is true, one's are placed in the cells of the matrix; for periods in which the effectivity is false, zero's are placed in the cells of the matrix.

[054] In the next stage, resulting matrix 1070 is constructed by logically evaluating the restriction bit rows of the production restriction matrix 1050 with the effectivity matrix 1060 and the order restriction matrix 1040. Table 1070 is generated by the following process for each order:

- For the order to be checked, read the corresponding column from Table 1040;
- For each "1" entry, select both the corresponding evaluation bit vector from the restriction matrix 1050 and the bit mask vector from matrix 1060 and combine them with the OR NOT function to reach an intermediate result bit vector;
- AND all of the intermediate result bit vectors yielding the result bit vectors in matrix 1070; and
- Repeat for each order.

[055] In this example, Table 1040 shows that Order 1 invokes effectivity 1 only. Therefore, take the bit vector from Table 1050 (011011) and OR this with NOT (111000), yielding (011111). Thus, Order 1 can be fulfilled anytime on or after 6/29. Order 2 invokes effectivity 2 only. Therefore, take the bit vector from Table 1050 (011011) and OR this with NOT (000111), yielding (111011). Thus, Order 2 can be fulfilled anytime prior to or after 7/1. Order 3 invokes effectivity 1 and 2. Therefore, take the logical AND of ((011011) OR NOT (111000)) and ((011011) OR NOT (000111)) to yield (011011). This makes logical sense because Order 3 is requesting both a luxury

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and a sport package so that no matter when the order is placed, alloy wheels are required.

[056] Once an order is placed or rescheduled by choosing an available production slot, as determined from Table 1070, one must determine whether the Table 1050 entry needs to be decremented. The table only needs to be decremented if the production slot corresponds to a production slot where the effectivity/restriction combination for that order is a "1". For example, examining table 1070, one may decide to place order 1 on June 29. If this is the case, we examine the entry in table 1040 to note that order 1 requires restriction 1 during this effectivity period, prior to July 1. Therefore, restriction 1 in table 1050 needs to be decremented on June 29. Likewise, if order 2 is placed on June 29, we examine the entry in table 1040 to note that order 2 only has restriction 1 during effectivity period 2; therefore, since the order is being placed during effectivity period 1, no decrement is necessary. Placing order 2 on June 29 does not require the restriction of alloy 2.

#### Implementation

[057] The above-noted features and other aspects and principles of the present invention may be implemented in various system or network environments to provide automated computational tools to facilitate data collection and risk analysis. Such environments and applications may be specially constructed for performing the various processes and operations of the invention or they may include a general purpose computer or computing platform selectively activated or reconfigured by program code to provide the necessary functionality. The processes disclosed herein are not inherently related to any particular computer or other apparatus, and may be

implemented by a suitable combination of hardware, software, and/or firmware. For example, various general purpose machines may be used with programs written in accordance with teachings of the invention, or it may be more convenient to construct a specialized apparatus or system to perform the required methods and techniques. The present invention also relates to computer readable media that include program instruction or program code for performing various computer-implemented operations based on the methods and processes of the invention. The media and program instructions may be those specially designed and constructed for the purposes of the invention, or they may be of the kind well-known and available to those having skill in the computer software arts. Examples of program instructions include both machine code, such as produced by compiler, and files containing a high level code that can be executed by the computer using an interpreter.

[058] By way of a non-limiting example, Figure 11 illustrates a system environment in which the features and principles of the present invention may be implemented. As illustrated in the block diagram of Figure 11, a system environment consistent with the present invention includes an input module 1110, an output module 1120, a computing platform 1110, and a database 1140. Computing platform 1110 is adapted to include the necessary functionality and computing capabilities to analyze each users information or data provided through input module 1110 and determine fitting gear using database 1140. The results of analyzing the data are provided as output from computing platform 1110 to output module 1120 for printed display, viewing or further communication to other system devices. Such output may include, for example, one or more recommended gear items or a comparative list of gear items as

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location or at a geographically distant location from input module 1110 and/or output module 1120.

[061] Input module 1110 of the system environment may shown in Figure 11 be implemented with a wide variety of devices to receive and/or provide the data as input to computing platform 1130. As illustrated in Figure 11, input module 1110 includes an input device 1111, a storage device 1112, and/or a network interface 1111. Input device 1111 may comprise a keyboard, a mouse, a disk drive, video camera, magnetic card reader or any other suitable input device for providing customer data to computing platform 1130. Memory device may be implemented with various forms of memory or storage devices, such as read-only memory (ROM) devices and random access memory (RAM) devices. Storage device 1112 may include a memory tape or disk drive for reading and providing customer or credit data on a storage tape or disk as input to computing platform 1120. Input module 1110 may also include network interface 1111, as illustrated in Figure 11, to receive data over a network (such as a LAN, WAN, intranet or the Internet) and to provide the same as input to computing platform 1130. For example, network interface 1111 may be connected to a public or private database over a network for the purpose of receiving and transferring customer or credit data to computing platform 1130.

[062] As illustrated in Figure 11, output module 1120 includes a display 1121, a printer device 1122, and/or a network interface 1123 for receiving the results provided as output from computing module 1120. As indicated above, the output from computing platform 1130 may include one or more recommended gear items and/or information about the gear items. The output from computing platform 1130 may be displayed or

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contemplated that these programs modules may be implemented using commercially available software tools, using custom object-oriented code written in the C++ programming language, using applets written in the Java programming language, or may be implemented as with discrete electrical components or as one or more hardwired application specific integrated circuits (ASIC) custom designed just for this purpose.

[066] In the foregoing Description of Preferred Embodiments, various features of the invention are grouped together in a single embodiment for purposes of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the following claims are hereby incorporated into this Description of the Preferred Embodiments, with each claim standing on its own as a separate preferred embodiment of the invention.

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